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# Control of wire melting behavior using coaxial hybrid solid wire<sup>†</sup>

—Development of pure Ar-MIG welding—

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**KEY WORDS:** (MIG arc welding) (Pure Ar) (Shielding gas) (Column of liquid metal) (Wire melting behavior)(Coaxial hybrid solid wire) (Instability) (Simulation)

## 1. Introduction

Coaxial hybrid solid (CHS) wires have been developed to carry out stable MIG welding in pure Ar shielding gas [1, 2]. The characteristics of weld metal are improved using MIG welding in pure Ar shielding gas (Ar-MIG welding) because the amount of oxygen in weld metal, which deteriorates the characteristics of weld metal, decreases [3]. However, the Ar-MIG welding is not used because of arc instability. If we use a conventional solid wire, a column of liquid metal (CLM) occurs at the wire tip (**Fig. 1**). This CLM makes the Ar-MIG welding unstable. In order to stabilize the Ar-MIG welding, shortening of the CLM is indispensable.

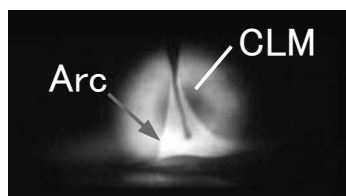
To shorten the CLM, the CHS wires (**Fig. 2**) have been developed [1, 2]. The composition of the inner part and the outer part are selected so that the amount of melting at the inner part may increase more than that of melting at the outer part. Instead of generating the CLM, a big droplet was then obtained (**Fig. 2**). As a result, stable Ar-MIG welding was achieved.

The melting behavior depends on physical properties of inner materials and outer materials, such as melting

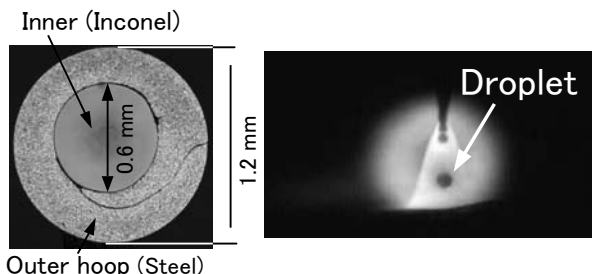
temperature, specific heat and thermal conductivity. We discuss the influence of material properties on wire melting behavior using a wire melting model of CHS wire [4] and develop the design guide for CHS wire.

## 2. Wire melting behavior of CHS wire

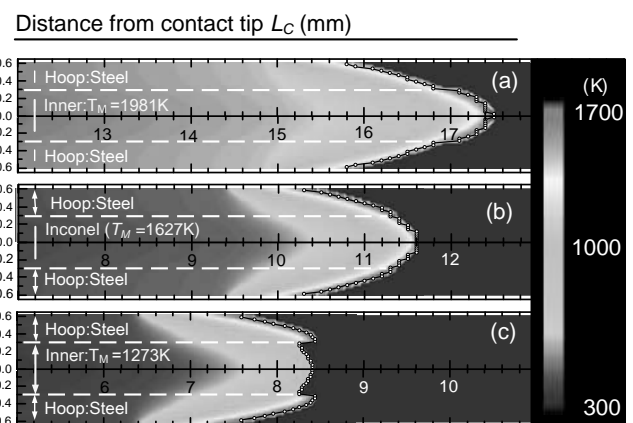
In order to investigate the influence of the material properties on wire melting behavior, the simulation is carried out [4]. First, we investigate the effect of melting temperature. We changed the melting temperature at the inner part. The wire tip shape and temperature distribution are shown in **Fig. 3**. The result of Inconel-Steel CHS wire is shown in **Fig. 3(b)**. The melting temperature at the inner part is set higher than the melting temperature of Inconel (**Fig. 3(a)**). The wire tip shows the convex shape. The CLM is made easily because the inner part becomes long. The melting temperature at the inner part is set lower than the melting temperature of Inconel (**Fig. 3(c)**). The CLM is not made because the wire tip shows the concave shape. It is effective to use the low melting temperature materials at the inner part to shorten the CLM.



**Fig. 1** Welding behavior of Ar-MIG welding using conventional solid wire.



**Fig. 2** Cross-section of CHS wire and welding behavior of Ar-MIG welding.



**Fig. 3** Effect of the melting temperature at the inner part on the wire melting behavior ( $I = 280$  A).

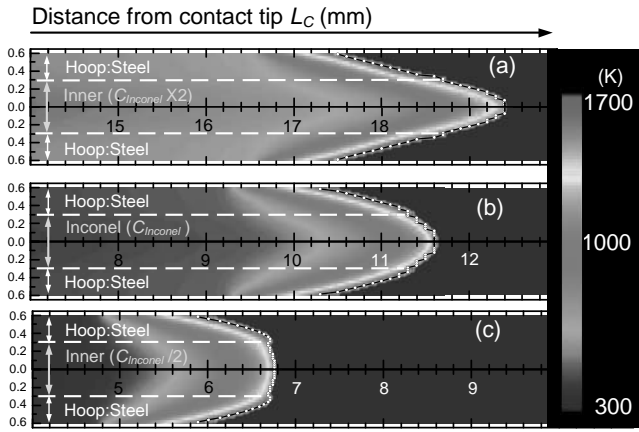
Next, we show the effect of the specific heat. We changed the specific heat at the inner part. **Figure 4** shows the results. The result of Inconel-Steel CHS wire is shown

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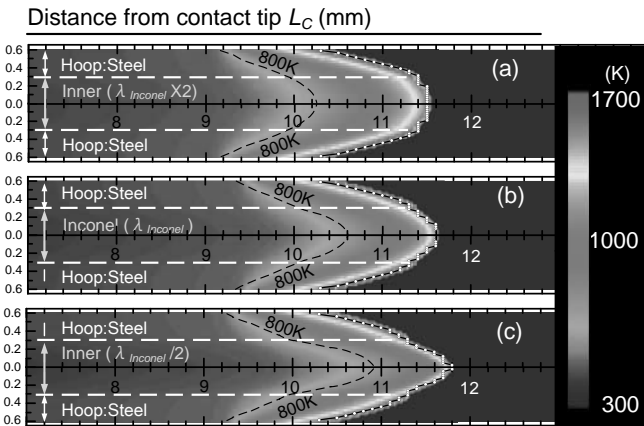
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**Fig. 4** Effect of the specific heat at the inner part on the wire melting behavior ( $I=280$  A).



**Fig. 5** Effect of the thermal conductivity at the inner part on the wire melting behavior ( $I=280$  A).

in Fig. 4(b). The specific heat at the inner part was set to twice the specific heat of Inconel (Fig. 4(a)). The wire tip shows the convex shape. The CLM is made easily because the inner part becomes long. In contrast, the specific heat at the inner part was set in half of the specific heat of Inconel (Fig. 4(c)). The CLM is not made because the wire tip shows the trapezoidal shape. It is effective to use the small specific heat materials at the inner part to shorten the CLM.

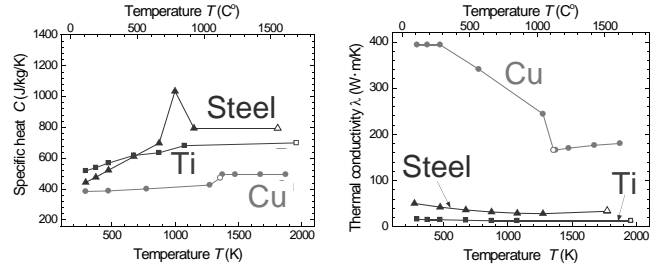
Last, we show the effect of thermal conductivity. We changed the thermal conductivity at the inner part. **Figure 5** shows the results. The result of Inconel-Steel CHS wire is shown in Fig. 5(b). The thermal conductivity at the inner part was set to twice the thermal conductivity of Inconel (Fig. 5(a)). The thermal conductivity at the inner part was set in half of the thermal conductivity of Inconel (Fig. 5(c)). The tip shape shown in Fig. 5(a) is round. However, the tip of shape shown in Fig. 5(c) is sharp, and the CLM is made easily because the inner part becomes long. The influence of thermal conductivity is not large, compared to the melting temperature and thermal conductivity.

## 3. Design guide to develop the CHS wire

In order to shorten the CLM in Ar-MIG welding, we must select appropriate materials for the inner part and the outer part. Then, we propose the design guide shown in **Table 1**. To develop a new CHS wire, we choose materials

**Table 1** Design guide of CHS wire.

	Melting temperature	Specific heat	Thermal conductivity
Inner part	Low	Small	Large
Outer part	High	Large	Small

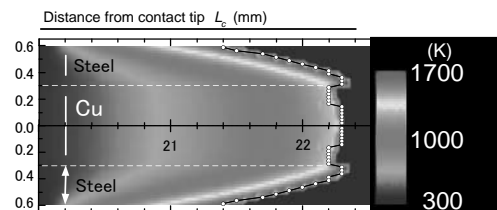


(a) Specific heat (b) Thermal conductivity

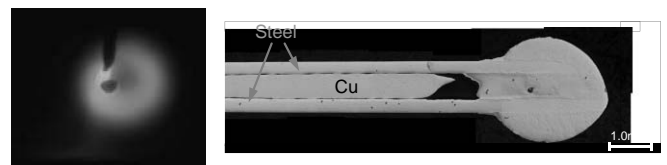
**Fig. 6** Material properties of Cu, Steel and Ti.

which are satisfied with design guide. Three materials (Cu, Steel and Ti) are used. The melting temperature of Cu, Steel and Ti are 1356 K, 1773 K and 1958 K, respectively. Specific heat and thermal conductivity are shown in **Fig. 6**. To shorten the CLM, we selected the Cu for the inner part materials because of following reasons. (i) Melting temperature is low, (ii) Specific heat is small, (iii) Thermal conductivity is large. The outer part is Ti or Steel. The melting temperatures of both materials are higher than that of Cu. The specific heat of steel is larger than that of Ti. Thermal conductivities of both materials are almost same level. The effect of specific heat is larger than that of thermal conductivity. Therefore, we select steel for the outer part.

In order to investigate wire melting behavior, the simulation was carried out. The result is shown in **Fig. 7**. The wire tip showed concave shape. So a long CLM was not made in this Cu-Steel CHS wire.



**Fig. 7** Simulation of Cu-Steel CHS wire ( $I=280$  A).



(a) Welding behavior (b) Longitudinal section of wire

**Fig. 8** Welding result of Cu-Steel CHS wire ( $I=291$  A).

We made Cu-Steel CHS wire to confirm the design guide of the CHS wire. The welding behavior is shown in **Fig. 8(a)**. The CLM did not occur and stable welding was possible. **Fig. 8(b)** shows longitudinal section of wire after the welding. The amount of melting at center the part was large.

#### 4. Conclusions

- (1) The melting temperature and the specific heat have a large influence on the wire tip shape, the wire melting rate and generation of CLM
- (2) The thermal conductivity has an influence on the wire tip shape, but the influence is small, compared to the

melting temperature and thermal conductivity.

- (3) The design guide for CHS wire is developed, and we demonstrate the effectiveness of design guide by the simulation and the Ar-MIG welding.

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